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(54) **System and scheduler for intercell interference cancellation**

(57) Embodiments of the invention provide a controller, in a cellular wireless network for cancellation of interference from neighboring cells. Logic in the controller determines channel quality of a radio channel between a first base station and a UE. Scheduling logic causes the first base station to adjust a number of data streams used for communication with the UE and a second base station to adjust a number of data streams used for communication to a second UE within a time period, as a

function of the channel quality. Other embodiments provide an apparatus for reducing interference in a receiver that receives N data streams. Signal processing logic receives the N data streams, where N-M of the data streams represent interference with respect to M desired data streams, and cancels the N-M data streams so as to receive the M desired data streams. The N data streams may be received from multiple base stations, or multiple UEs.

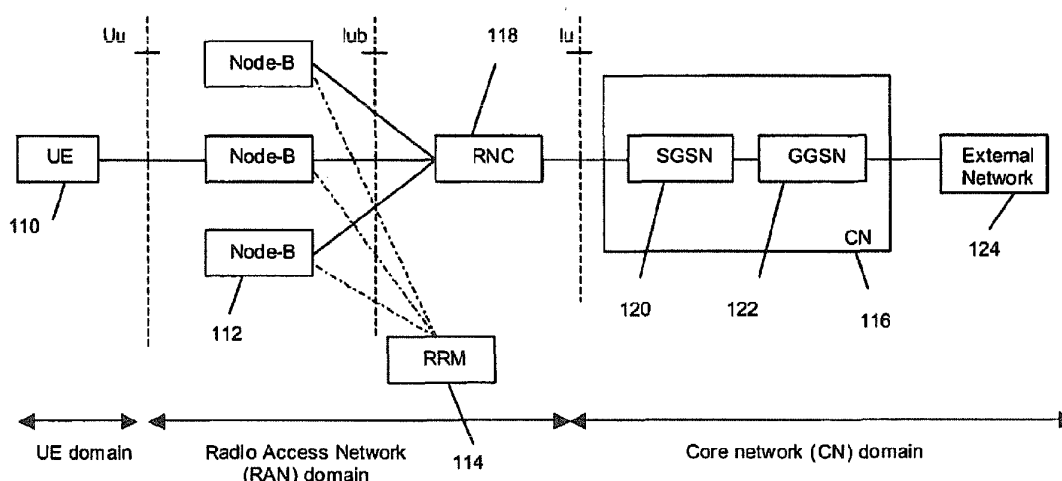


Figure 2A

Description**BACKGROUND OF THE INVENTION**

[0001] The invention relates to cancellation of interference from neighboring cells in a wireless communications system.

[0002] It is well known that the performance of cellular systems is limited due to the presence of intercell interference. For example, in the downlink, users at the edge of the cell may experience interference from neighboring cells at received power levels similar to that of the signal from the serving cell. This is especially the case for densely planned systems employing low frequency-reuse factors. Indeed, in the limit, a frequency reuse of one may be used. While a reuse of one is desirable to maximize the amount of time/frequency resources available to each cell in the system, the intercell interference problem it creates naturally results in a lowering of the data rates achievable for users at the edges of the cell. Transmissions to users with low signal to noise plus interference ratios (SNIR) require information redundancy and hence a low code rate to achieve the desired decoding quality (measured for example as block error rate, BLER), resulting in a corresponding reduction in the data rate.

[0003] The use of multiple-input multiple-output (MIMO) antenna systems is also well known. In these systems, data may be transmitted to a user over sets of channels existing between n_{Tx} transmit antennas and n_{Rx} receive antennas. There are thus a total of $n_{Tx} \times n_{Rx}$ channels which make up the composite MIMO channel set. Multiple simultaneous data streams may be transmitted over the channel set if the channels of the set are sufficiently statistically independent and uncorrelated.

[0004] It is further well known that the ability of the system to successfully transmit multiple simultaneous and different data streams over the MIMO channel set is also a function of the channel SNIR. Successful transmission of parallel streams is more likely in channels with high SNIR and less likely in channels with low SNIR. Thus, the gain of MIMO transmission (in terms of achievable link throughput), compared to its transmit and receive diversity counterparts, is increased for cases of higher SNIR and higher channel decorrelation. For low SNIR or high channel correlation, the gains of MIMO diminish and instead transmission of a single data stream can result in better overall performance than transmission of multiple parallel data streams, and thus is preferred. Note that the multiple channels in the set may still be used to provide transmit/receive diversity benefits; however, no attempt is made to transmit multiple parallel data streams in this case.

[0005] Figures 1A and 1B illustrate one example of two-stream MIMO transmission over a 2x2 channel set, and one example of single-stream non-MIMO transmission over the same channel set, respectively. The primary difference is that in the two-stream MIMO case, each transmit antenna is conveying different information, whereas in the single stream case, the information transmitted by each antenna is the same (although the actual signal waveforms may differ).

[0006] It is further known that systems may dynamically switch between single and multi- (e.g. dual) stream transmission according to variations observed in the channel SNIR or as the statistical correlation between the channels in the channel set is seen to vary. In this way, users experiencing poorer radio conditions (low SNIR and/or high channel correlation) will receive single-stream transmissions and users with good radio conditions (high SNIR and/or low channel correlation) will be able to exploit multi-stream transmission to achieve higher data rates and link throughput.

SUMMARY OF THE INVENTION

[0007] Embodiments of the invention provide a controller, in a cellular wireless network for cancellation of interference from neighboring cells. Logic in the controller determines channel quality of a radio channel between a first base station and a UE. Scheduling logic causes the first base station and a second base station to adjust the number of data streams used for communication within a time period, as a function of the channel quality.

[0008] In some embodiments, the scheduling logic instructs the first and second base stations to reduce the number of data streams used by each of the base stations in response to a low channel quality. The scheduling logic also instructs the first and second base stations to increase the number of data streams used by each of the base stations in response to a high channel quality.

[0009] Other embodiments provide an apparatus for reducing interference in a receiver that receives N data streams. Signal processing logic receives the N data streams, where N-M of the data streams represent interference with respect to M desired data streams, and cancels the N-M data streams so as to receive the M desired data streams. The N data streams may be received from multiple base stations, or multiple UEs.

BRIEF DESCRIPTION OF THE FIGURES

[0010]

Figure 1A illustrates an example of a two-stream MIMO transmission over a 2x2 channel set;

Figure 1B illustrates an example of a single-stream MIMO transmission over a 2x2 channel set;

Figure 2A illustrates a cellular communication system according to embodiments of the invention;

5 Figure 2B illustrates a cellular communication system according to 3GPP LTE specifications;

Figures 3A-3D illustrate examples of transmissions to a UE in different positions between two cells according to embodiments of the invention;

10 Figure 4 illustrates an embodiment of OFDM symbols, each with a pre-pended cyclic prefix portion;

Figure 5 illustrates embodiments of reception of signals from cell A and cell B that are substantially time-aligned;

15 Figure 6 illustrates an embodiment of a dual-stream transmission over a 2x2 channel system according to embodiments of the invention;

Figure 7 illustrates an embodiment of two single-stream transmissions over a 2x2 channel system according to embodiments of the invention; and

20 Figure 8 illustrates a computer system that may be employed to implement embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

25 **[0011]** Figure 2A illustrates an example of a cellular communication system according to embodiments of the invention. The network includes a user equipment (UE) domain, a radio access network (RAN) domain, and a core network domain. The UE domain includes user equipment 110 that communicates with at least one base station 112 in the RAN domain via a wireless interface. The RAN domain may also include a network controller 118 (e.g., radio network controller), such as that used in UMTS systems.

30 **[0012]** The core network (CN) 116 includes, in this example, a serving GPRS support node (SGSN) 120, and a gateway GPRS support node (GGSN) 122. The core network is coupled to an external network 124, such as the Internet. The SGSN 120 is responsible for session control, including keeping track of the location of the UEs. The GGSN 122 concentrates and tunnels user data within the core network 116 to the ultimate destination (e.g., an Internet service provider) in the external network 124.

35 **[0013]** Figure 2B illustrates an example of a system according to the 3GPP LTE specification. As in Figure 2A, the system includes UEs 150, Node Bs 151, an RRM 152, and an external network 154. This system also includes an access gateway (aGW) 153.

40 **[0014]** Further details regarding exemplary communications systems that may implement embodiments of the invention may be found in 3GPP UMTS technical specifications, such as TR 23.882, "3GPP System Architecture Evolution: Report on Technical Options and Conclusions"; TR 25.912, "Feasibility Study for Evolved UTRA and UTRAN"; TS 23.101, "General Universal Mobile Telecommunications System (UMTS) Architecture"; all of which are incorporated by reference herein.

45 **[0015]** According to embodiments of the invention, the scheduling of packets for transmission (including the allocation of resources) may be performed in a centralized or distributed manner within the system of Figure 2A or Figure 2B. In the centralized case, a single scheduler may have command over multiple cells or multiple Node Bs. In the distributed case, a single scheduler may have command only over one cell, or only over cells (i.e., sectors) of the same Node B. In the distributed case, the schedulers may communicate with one another, and pass relevant data among each other to assist with the scheduling process. This may be achieved via direct scheduler-to-scheduler interfaces, or the communication may pass through a common centralized point or node.

50 **[0016]** As an example of centralized coordination, the RRM function may be responsible in the RAN domain for high-level coordination and management of the user's usage of the available radio resources. A finer level of management of the radio resources may be performed by individual schedulers residing within each Node-B, RNC, or aGW, pursuant to instructions from the network component providing RRM coordination functionality. This RRM functionality may be provided by the separate RRM unit 114/152, or by a Node B, the RNC or the aGW acting as a "master" coordinator. Alternatively, such scheduling functionality (and the coordination thereof) may be distributed among the Node Bs, RNC, RRM or aGW or other controller in the core network. The RRM function may be located within the Node-Bs, within the aGW or RNC element, or within the separate RRM server element in the RAN domain (as shown), in which case the responsible network elements communicate among themselves to coordinate scheduling. In a particular example, the schedulers may be located in each Node B, in which case the Node Bs would communicate with each other to coordinate

scheduling.

[0017] Referring to Figures 1A and 1B, when a user is at the cell edge and experiencing poor radio conditions, single stream transmission may be used. However, in interference-limited systems (such as is common when designing for high capacity), the poor SNIR that the user is experiencing is often due not to thermal noise in the receiver but due to transmissions being made in neighboring cells (intercell interference). To the MIMO-capable user equipment (UE) receiver, this interfering signal can be considered to be a second data stream transmission although transmitted from a separate base station to the wanted data stream transmission from the serving cell. Thus two single stream transmissions from each of two cells can be considered to look like a two-stream transmission from a single cell. Consequently, the UE receiver is able to jointly estimate the data modulation symbols from both the serving and interfering cells and to cancel the interference being imparted on the serving cell transmission.

[0018] A UE receiver with two receive antennas is able to jointly detect up to two data streams. Attempts to detect more than two data streams results in an under-determined mathematical problem, for which the solutions calculated by the receiver may not be accurate. Thus, for this example, we assume that the UE can cancel $n_{RX}-1$ intercell streams if the serving cell is transmitting a single stream. In general, if the serving cell is transmitting M streams of interest to the UE, then the UE can cancel $n_{RX}-M$ intercell streams.

[0019] As to the current example, this implies that if the neighboring cell is transmitting two streams (and the serving cell only one), then the UE is only able to cancel one of the neighbor cell streams (and so perhaps only 50% of the interfering power from that cell).

[0020] In contrast, when the neighbor cell is also transmitting only a single stream (for example, it is also transmitting to a cell edge user), then there is the possibility for the UE to cancel up to 100% of the interfering power from that cell. It is therefore advantageous that when serving UEs that are experiencing high levels of interference, both the serving and interfering cells align their single stream transmissions and avoid overlapping of single stream transmission in a serving cell with dual (or multi-) stream transmission in an interfering cell on the same time/frequency resources. Note this does not require transmission from only a single antenna at each base station, just that a single information stream is transmitted over the (possibly) multiple antennas. Note that the above description is extensible (e.g. in the case of an increased number n_{RX} of antennas at the UE) such that when serving UEs that are experiencing high interference levels, the serving and interfering cells align their transmissions of a respective lower number N of streams from each of the cells (where N could be larger than 1) and overlapping of a low number of streams in the serving cell with a high number of streams in the interfering cell is avoided.

[0021] Figures 3A-D illustrate the situation where a mobile transceiver (UE) moves from good radio conditions in cell A, through the cell border between cells A and B, and on into the interior of cell B. Referring to Figure 3A, when the UE 306 is located well within cell A 302, the interference from cell B is weak, and cell A may use dual-stream MIMO transmission 308 to the UE 306. The receiver of the UE 306 does not try to detect the signal from cell B 304 and uses the available "degrees of freedom" in the receiver processing to jointly detect the two data streams from cell A 302. Cell B 304 is unrestricted regarding the number of streams it may transmit due to the fact that the UE 306 is not trying to detect the signal from cell B 304.

[0022] Referring to Figure 3B, at the cell border, the interference from cell B 304 is strong and cell A 302 changes to a single-stream transmission. A degree of freedom is released in the receiver of the UE 306 upon moving from dual-stream to single-stream 310 reception from cell A 302. The UE 306 may then jointly detect the single stream interfering transmission 312 from cell B 304 such that the interference may be cancelled to some degree. The schedulers controlling cell A 302 and cell B 304 are coordinated. The schedulers may be located within the Node-Bs or within the RNC or aGW and are coordinated via the RRM functionality. The RRM functionality may be distributed among the Node-Bs, or may be located within a centralized node such as an RNC, aGW or within a dedicated RRM server. Coordination between the schedulers may be effected to ensure that single-stream transmissions from cell A 302 coincide with single stream transmissions from cell B 304. This enables the UE 306 to cancel up to 100% of the power from cell B 304.

[0023] Referring to Figure 3C, at the cell borders, a handover occurs (the serving cell for the UE 306 changes from cell A 302 to cell B 304), and the UE 306 continues to jointly detect the data symbols of the single-stream transmissions from both cells 314, 316. Only now, cell A 302 is the interfering cell and cell B 304 contains the desired user data.

[0024] Referring to Figure 3D, as the UE 306 moves further into cell B 304, the radio conditions improve and the interference from cell A 302 weakens. Upon receiving information of this condition, the scheduler controlling cell B 304 may instruct the base station 318 controlling cell B 304 to switch to dual stream transmission 320 to the UE 306, and the UE 306 no longer needs to jointly detect both cells (only cell B 304 is actively detected by the UE 306 in this example). This decision may also be taken into account by the coordination functionality (e.g. RRM) such that cell A 302 is no longer restricted to transmission of a single stream (any number of streams may now be transmitted by cell A 302).

[0025] The RRM functionality (whether within a separate RRM server or distributed among other network elements) that coordinates the number of streams transmitted by each of the cells may be operable on a dynamic basis according to the particular channel conditions of users in the system requesting service. In this mode of operation, the RRM function may consider, on a short term basis, the traffic loading in each cell under its jurisdiction, the channel conditions of the

users that need to be served in the cells, and the physical resources available for communication.

[0026] In this mode, for example, assume two base stations each communicating in different, adjacent cells with a different UE over the same time/frequency/code resources. Thus, communications from one cell would be considered interference by the other cell. Also, assume that one UE had a strong channel connection with its base station, whereas the other UE had a weak channel connection with its own base station. In one embodiment of the system, both base stations would have a low number of data streams scheduled to accommodate the weak channel to reduce intercell interference.

[0027] Alternatively, the RRM functionality may operate on a slower "semi-static" basis, or even on a fixed basis. In these modes of operation, the RRM function may assign a portion of the total available physical resources (e.g. time/frequency/code resources) for UEs in poor channel conditions, while a separate portion of the total physical resources is reserved for UEs in good channel conditions. In other words, the UEs having strong channel conditions would not share all the same resources as the UEs having poor channel conditions. The assignments would typically apply to multiple cells that all lie within the jurisdiction of the RRM function. UEs in poor channel conditions are assigned to the physical resource portion reserved for poor UEs, whereas UEs in good channel conditions are assigned to the physical resource portion reserved for good UEs. A low number of data streams is transmitted in the portion assigned to poor UEs, and a higher number of data streams is transmitted in the portion assigned to good UEs, thus avoiding the "lowest common denominator" approach (discussed above) of assigning the same number of data streams to both "poor-channel" and "strong channel" UEs based upon the weaker channels. In this way, each scheduler may decide autonomously to schedule a UE under its control in one or the other physical resource portion safe in the knowledge that the number of streams transmitted by another cell on the same physical resources will be appropriate for the channel conditions being experienced by the UE. Updates to the amount of physical resources reserved for each portion may be made relatively slowly by the RRM function in response to the observed proportion of users experiencing good and bad channel conditions respectively. Categorization of each UE may be made by the schedulers to continually reassign users to the appropriate physical resource portion according to any updated channel condition information received.

[0028] Figure 4 depicts orthogonal frequency division multiplexing (OFDM) symbols, each with a pre-pended cyclic prefix portion. Embodiments of the present invention may be employed in any cellular system, including those using code division multiple access (CDMA) or OFDM modulation schemes. In particular as to OFDM, such a system employs the transmission of data symbols over multiple orthogonal narrow-band sub-carriers. An OFDM "symbol" 402 lasts for time T_u and comprises a cyclic prefix portion 404 which is used to allow for so-called multi-path energy over the channel dispersion length to be easily combined in the receiver without the multi-path components impacting adjacent OFDM symbols in time.

[0029] In OFDM systems, data is transmitted across multiple parallel narrow-band sub-carriers by modulating each data symbol with an orthogonal complex exponential (tone). The sub-carriers are orthogonal to each other by virtue of the orthogonal modulation waveforms, and hence, under reasonable radio conditions, it may be ensured that each symbol does not cause interference with other symbols transmitted at the same time on other sub-carriers. Assuming each OFDM symbol occupies K subcarriers, K data modulation symbols are typically transmitted per OFDM symbol. A data modulation symbol may be, for example, a QPSK symbol (carrying 2 bits), or a 16-QAM symbol (carrying 4 bits).

[0030] The sub-carrier bandwidth is typically narrow such that in commonly-experienced multipath (frequency selective) radio channels, the individually-arriving channel rays (in time) are shorter than the fundamental period of the receiver's time-domain pulse shape for each sub-carrier. Hence the channel rays are not resolvable once the receiver filter has been applied. Thus, the multi-path signal components become summed for each narrow-band sub-carrier as a natural part of the receiver processing. In many channel types this results in a flat-fading characteristic for each sub-carrier with a mean composite channel power equal to the summation of the powers of the contributing channel paths. This aspect, wherein multiple arriving signal paths are naturally combined within the narrow sub-carrier bandwidth, may be exploited to allow for signals carrying the same modulation symbol (same content) to be combined as a natural part of the receiver processing. No additional or special processing is required to combine the energy of the multiple copies of the signal. This includes both the case where multiple copies of the signal arrive due to time dispersion in the radio channel, and the case where multiple copies of the same signal arrive due to them having been intentionally transmitted from different sources/antennas over different channels.

[0031] Referring to Figure 5, the signal from cell A 502 and the signal from cell B 504 are substantially time-aligned such that at the receiver they arrive within the cyclic prefix duration. The cyclic prefixes 506 of the cell A signal 502 may be substantially aligned with the cyclic prefixes 508 of the cell B signal 504. This may be achieved by means of synchronizing cells A and B as is commonly performed in cellular networks. Synchronisation may be achieved by aligning the timing of each of the cells with a common reference time signal such as GPS, or a network clock. Other methods of synchronization are also possible wherein the cells communicate timing messages with one another enabling early/late adjustments to be made and for the system to self-coordinate its timing without the use of a common clock. When the signals are synchronized such that they arrive at the UE receiver within the cyclic prefix duration, this allows for the signals to be combined (summed) without additional processing. For other modulation systems (e.g. FDMA or CDMA),

substantial time alignment may be considered to be an alignment of the signals such that they fall within an equalizer time window or similar time period, allowing for the receiver to capture the energy arriving from both cells.

[0032] The multi-carrier OFDM system can be modeled simply as multiple individual narrow-band single carrier systems.

5 **[0033]** The system model for a single sub-carrier is:

$$\underline{r} = H\underline{s} + \underline{n}$$

10 **[0034]** Here, \underline{r} is a vector of size $n_{Rx} \times 1$ and contains the received signal at each of the UE receiver antennas. \underline{s} is the $n_{Tx} \times 1$ vector of transmitted data symbols (one for each basestation Tx antenna) and \underline{n} is a vector of noise samples (size $n_{Rx} \times 1$).

[0035] H is the channel matrix of size $n_{Rx} \times n_{Tx}$.

15 **[0036]** Figure 6 illustrates a dual stream transmission in cell A 602 over a 2x2 channel system.

[0037] The system is modeled according to the equation below

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{A1,1} & h_{A2,1} \\ h_{A1,2} & h_{A2,2} \end{bmatrix} \times \begin{bmatrix} s_{A1} \\ s_{A2} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

25 **[0038]** Here, $h_{Ai,j}$ represents the channel from cell A antenna i to UE receive antenna j . s_{Ai} represents the signal transmitted from cell A antenna i .

[0039] Given the received signal \underline{r} , estimates of \underline{s} may be calculated in several ways. These include the zero-forcing (ZF), Minimum Mean Square Error (MMSE) and Maximum Likelihood (ML) techniques. The following equations employ the zero forcing approach, as it represents the simplest case for descriptive purposes.

30 **[0040]** As the channel matrix H is square, an inverse may be calculated H^{-1} such that $H \times H^{-1}$ is equal to the identity matrix (I).

[0041] Then, the ZF solution to the problem is:

$$\begin{bmatrix} \hat{s}_{A1} \\ \hat{s}_{A2} \end{bmatrix} = \begin{bmatrix} h_{A1,1} & h_{A2,1} \\ h_{A1,2} & h_{A2,2} \end{bmatrix}^{-1} \times \begin{bmatrix} r_1 \\ r_2 \end{bmatrix}$$

40 **[0042]** Now, referring to Figure 7, consider the case of two single stream transmissions, one from cell A 702 and one from cell B 704. Each is over its own 2x2 channel system.

[0043] In this case, the system is modeled as:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{A1,1} & h_{A2,1} & h_{B1,1} & h_{B2,1} \\ h_{A1,2} & h_{A2,2} & h_{B1,2} & h_{B2,2} \end{bmatrix} \times \begin{bmatrix} s_{A1} \\ s_{A2} \\ s_{B1} \\ s_{B2} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

55 **[0044]** However, in the single stream case, the same symbol is transmitted from all antennas of the same basestation. Thus, $s_{A1} = s_{A2} = s_A$ and $s_{B1} = s_{B2} = s_B$.

[0045] This means that the above system equation reduces to:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} (h_{A1,1} + h_{A2,1})(h_{B1,1} + h_{B2,1}) \\ (h_{A1,2} + h_{A2,2})(h_{B1,2} + h_{B2,2}) \end{bmatrix} \times \begin{bmatrix} s_A \\ s_B \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

[0046] Again the channel matrix is square and so an inverse may be found. The zero forcing estimate of the transmitted symbol vector $[s_A, s_B]$ in this case is:

$$\begin{bmatrix} \hat{s}_A \\ \hat{s}_B \end{bmatrix} = \begin{bmatrix} (h_{A1,1} + h_{A2,1})(h_{B1,1} + h_{B2,1}) \\ (h_{A1,2} + h_{A2,2})(h_{B1,2} + h_{B2,2}) \end{bmatrix}^{-1} \times \begin{bmatrix} r_1 \\ r_2 \end{bmatrix}$$

[0047] Thus, the UE receiver 706 for the two single stream case (from different cells) is very similar to that of the two stream case (from a single cell) and can be used to cancel interference from one neighbor cell.

[0048] While the invention has been described in terms of particular embodiments and illustrative figures, those of ordinary skill in the art will recognize that the invention is not limited to the embodiments or figures described. Although embodiments of the present invention are described, in some instances, using UMTS terminology, those skilled in the art will recognize that such terms are also used in a generic sense herein, and that the present invention is not limited to UMTS or 3G systems.

[0049] Those skilled in the art will recognize that the operations of the various embodiments may be implemented using hardware, software, firmware, or combinations thereof, as appropriate. For example, some processes can be carried out using processors or other digital circuitry under the control of software, firmware, or hard-wired logic. (The term "logic" herein refers to fixed hardware, programmable logic and/or an appropriate combination thereof, as would be recognized by one skilled in the art to carry out the recited functions.) Software and firmware can be stored on computer-readable media. Some other processes can be implemented using analog circuitry, as is well known to one of ordinary skill in the art. Additionally, memory or other storage, as well as communication components, may be employed in embodiments of the invention.

[0050] Figure 8 illustrates a typical computing system 800 that may be employed to carry out processing functionality in embodiments of the invention. Those skilled in the relevant art will also recognize how to implement the invention using other computer systems or architectures. Computing system 800 may represent, for example, a desktop, laptop or notebook computer, hand-held computing device (PDA, cell phone, palmtop, etc.), mainframe, supercomputer, server, client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or environment. Computing system 800 can include one or more processors, such as a processor 804. Processor 804 can be implemented using a general or special purpose processing engine such as, for example, a microprocessor, controller or other control logic. In this example, processor 804 is connected to a bus 802 or other communication medium.

[0051] Computing system 800 can also include a main memory 808, preferably random access memory (RAM) or other dynamic memory, for storing information and instructions to be executed by processor 804. Main memory 808 also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by processor 804. Computing system 800 may likewise include a read only memory ("ROM") or other static storage device coupled to bus 802 for storing static information and instructions for processor 804.

[0052] The computing system 800 may also include information storage mechanism 810, which may include, for example, a media drive 812 and a removable storage interface 820. The media drive 812 may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an optical disk drive, a CD or DVD drive (R or RW), or other removable or fixed media drive. Storage media 818, may include, for example, a hard disk, floppy disk, magnetic tape, optical disk, CD or DVD, or other fixed or removable medium that is read by and written to by media drive 814. As these examples illustrate, the storage media 818 may include a computer-readable storage medium having stored therein particular computer software or data.

[0053] In alternative embodiments, information storage mechanism 810 may include other similar instrumentalities for allowing computer programs or other instructions or data to be loaded into computing system 800. Such instrumentalities may include, for example, a removable storage unit 822 and an interface 820, such as a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory module) and memory slot, and other removable storage units 822 and interfaces 820 that allow software and data to be transferred from the

removable storage unit 818 to computing system 800.

[0054] Computing system 800 can also include a communications interface 824. Communications interface 824 can be used to allow software and data to be transferred between computing system 800 and external devices. Examples of communications interface 824 can include a modem, a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a USB port), a PCMCIA slot and card, etc. Software and data transferred via communications interface 824 are in the form of signals which can be electronic, electromagnetic, optical or other signals capable of being received by communications interface 824. These signals are provided to communications interface 824 via a channel 828. This channel 828 may carry signals and may be implemented using a wireless medium, wire or cable, fiber optics, or other communications medium. Some examples of a channel include a phone line, a cellular phone link, an RF link, a network interface, a local or wide area network, and other communications channels.

[0055] In this document, the terms "computer program product" and "computer-readable medium" may be used generally to refer to media such as, for example, memory 808, storage device 818, storage unit 822, or signal(s) on channel 828. These and other forms of computer-readable media may be involved in providing one or more sequences of one or more instructions to processor 804 for execution. Such instructions, generally referred to as "computer program code" (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system 800 to perform features or functions of embodiments of the present invention.

[0056] In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system 800 using, for example, removable storage drive 814, drive 812 or communications interface 824. The control logic (in this example, software instructions or computer program code), when executed by the processor 804, causes the processor 804 to perform the functions of the invention as described herein.

[0057] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

[0058] Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the invention.

[0059] Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather the feature may be equally applicable to other claim categories, as appropriate.

[0060] Further aspects and features of the invention are set out in the following numbered clauses:

1. A controller in a cellular wireless network, the controller comprising:

logic for determining channel quality of a radio channel between a first base station and a user equipment (UE); wherein the controller is characterized by:

scheduling logic for causing the first base station to adjust a number of data streams used for communication with the UE and a second base station to adjust a number of data stream used for communication with a second UE within a time period, as a function of the channel quality.

2. The controller of clause 1 wherein the channel quality is represented by a carrier-to-interference ratio.

3. The controller of clause 1 or clause 2, wherein the logic for determining the channel quality is operable to receive a signal quality report from the UE indicative of a quality of signals received by the UE from the first base station.

4. The controller of any preceding clause, wherein

the logic for determining channel quality is operable to determine a first channel quality for the first base station communicating with a first UE, and a second channel quality for the second base station communicating with a second UE, the first and second base station serving adjacent cells; and the scheduling logic is operable to cause the first and second base stations to adjust the number of data streams

based upon the poorest channel quality of the first and second channel qualities.

5. The controller of any preceding clause, wherein the scheduling logic is operable to schedule designated resources corresponding to the channel quality.

6. The controller of any preceding clause, wherein the scheduling logic is operable to instruct the first and second base stations to reduce the number of data streams used by each of the base stations in response to a low channel quality; or instruct the first and second base stations to increase the number of data streams used by each of the base stations in response to a high channel quality.

7. The controller of clause 6, wherein the low channel quality is indicative of the channel quality falling below a threshold, and the high channel quality is indicative of the channel quality exceeding a threshold.

8. The controller of any preceding clause, wherein the first base station is associated with a serving cell, and the second base station represents an interfering cell

9. The controller of any preceding clause, wherein the data streams are substantially time-aligned.

10. The controller of any preceding clause, wherein substantial time-alignment of the data streams is based upon the cyclic prefix period in an Orthogonal Frequency Division Multiplexing (OFDM) symbol.

11. The controller of any preceding clause, wherein the data streams are subject to OFDM modulation.

12. The controller of any preceding clause, wherein the data streams are subject to Code Division Multiple Access (CDMA) modulation.

13. A radio network controller (RNC) in a radio access network, wherein the RNC comprises the controller of any preceding claim.

14. A base station in a wireless communications network, wherein the base station comprises the controller of any of preceding clauses 1 to 12.

15. An access gateway (aGW) in a wireless communications network, wherein the aGW comprises the controller of any of preceding clauses 1 to 12.

16. A radio resource management (RRM) server in a wireless communications network, wherein the RRM server comprises the controller of any of preceding clauses 1 to 12.

17. An apparatus for reducing interference in a cellular wireless network, the apparatus comprising signal processing logic for:

receiving N data streams, wherein N-M of the data streams represent interference with respect to M desired data streams;
wherein the apparatus is characterized by signal processing logic for canceling the N-M data streams so as to receive the M desired data streams, wherein the logic for receiving the N data streams is operable to receive the N data streams.

18. The apparatus of clause 17, wherein the receiver resides in a user equipment (UE), and the signal processing logic is further operable to:

provide a signal quality report to at least one base station, the signal quality report indicative of the quality of a channel between the UE and the at least one base station; and receive at least one instruction to communicate M desired data streams with the at least one base station, wherein the at least one instruction is based upon the signal quality report.

19. The apparatus of clause 17 or clause 18, wherein the receiver is a UE.

20. The apparatus of any of preceding clauses 17 to 18, wherein the receiver resides in a base station.

21. The apparatus of any of preceding clauses 17 to 20, wherein the receiver includes a multiple-input multiple-output (MIMO) receiver.

22. The apparatus of any of preceding clauses 17 to 21, wherein the N data streams are substantially time-aligned.

23. The apparatus of any of preceding clauses 17 to 22, wherein N represents a maximum data stream capacity of the receiver.

24. The apparatus of any of preceding clauses 17 to 23, wherein the data streams are subject to OFDM modulation.

25. The apparatus of any of preceding clause 17 to 23, wherein the data streams are subject to CDMA modulation.

26. The apparatus of any of preceding clauses 17 to 25, wherein the N data streams are from a plurality of base stations.

27. The apparatus of any of preceding clauses 17 to 25, wherein the N data streams are from a plurality of UEs.

28. A method for scheduling resources in a cellular wireless network, the method comprising:

determining channel quality of a radio channel between a first base station and a UE; wherein the method is characterized by:-

causing the first base station to adjust a number of data streams used for communication with the UE and causing a second base station to adjust a number of data streams for communication with a second UE, within a time period, as a function of the channel quality.

29. The method of clause 28, wherein causing the first base station and a second base station to adjust the number of data streams used for communication within a time period includes scheduling designated resources corresponding to the channel quality.

30. The method of clause 28 or clause 29, wherein determining the channel quality comprises receiving a signal quality report from the UE indicative of the quality of signals received by the UE from the first base station.

31. The method of any of preceding clauses 28 to 30, wherein the first base station is associated with a serving cell, and the second base station represents an interfering cell

32. The method of any of preceding clauses 28 to 31, wherein the data streams are substantially time-aligned.

33. A computer readable medium encoded with program instructions for carrying out the method of any of the preceding clauses 28 to 32.

34. A method for reducing interference in a cellular wireless network, the method comprising:

receiving N data streams, wherein N-M of the data streams represent interference with respect to M desired data streams; wherein the method is characterized by:

canceling the N-M data streams so as to receive the M desired data streams, wherein the logic for receiving the N data streams is operable to receive the N data streams from a plurality of base stations.

35. The method of clause 34, wherein the receiver resides in a UE, the method further comprising:

providing a signal quality report to at least one base station, the signal quality report indicative of the quality of a channel between the UE and the at least one base station; and receiving at least one instruction to communicate M desired data streams with the at least one base station, wherein the at least one instruction is based upon the signal quality report.

36. A computer readable medium encoded with program instructions for carrying out the method of clause 34 or clause 35.

5 Claims

1. A controller (118) in a cellular wireless network, the controller (118) comprising:

logic arranged to determine channel quality of a first radio channel between a first base station (112, 151) and a first user equipment, UE (110); wherein the controller (118) is **characterised by**:

scheduling logic operating in a coordinated manner between the first base station and a second base station so that a single stream transmission between the first base station and the first user equipment coincides with single stream transmissions from the second base station;

wherein the data streams are subject to Orthogonal Frequency Division Multiplexing, OFDM, modulation.

2. The controller (118) of claim 1, wherein the scheduling logic is operable to assign in common to multiple cells of the cellular wireless network a first portion of physical resources for user equipment in poor channel conditions, and a separate second portion of the physical resources for user equipment in good channel conditions, wherein a higher number of data streams are transmitted from the base station in the portion of physical resources assigned to good channel conditions than in the portion of physical resources assigned to poor channel conditions, to assign user equipment categorised by the determined channel quality to be in poor channel conditions to the first portion of physical resources and to assign user equipment categorised by the determined channel quality to be in good channel conditions to the second portion of physical resources.

3. The controller (118) of claim 2, wherein the scheduling logic is operable to reassign the user equipment between the first portion of physical resources and the second portion of physical resources according to any updated channel condition information relating to the user equipment.

4. The controller (118) of claim 2 or claim 3, wherein the scheduling logic is operable to update the amount of physical resources reserved for each of the first and second portions of physical resources in response to an observed proportion of users experiencing good and bad channel conditions.

5. The controller (118) of claim 1, wherein the logic for determining the first radio channel quality is arranged to receive a signal quality report from the first UE (110, 150) indicative of a quality of signals received by the first UE (110, 150) from the first base station (112, 151).

6. The controller (118) of any preceding claim, wherein the scheduling logic is arranged to schedule designated resources corresponding to the determined channel quality.

7. The controller (118) of any preceding claim, wherein the scheduling logic is arranged to:

instruct the first base station and second base station to reduce the number of data streams used by each of the base stations in response to a low channel quality; or

instruct the first base station (112, 151) and second base station to increase the number of data streams used by each of the base stations in response to a high channel quality.

8. The controller (118) of claim 7, wherein the low channel quality is indicative of the determined channel quality falling below a threshold, and the high channel quality is indicative of the determined channel quality exceeding a threshold.

9. The controller (118) of any preceding claim, wherein the first base station (112, 151) is associated with a serving cell, and the second base station represents an interfering cell.

10. The controller (118) of any preceding claim, wherein the data streams are time-aligned.

11. The controller (118) of claim 10, wherein time-alignment of the data streams is based upon the cyclic prefix period in an Orthogonal Frequency Division Multiplexing, OFDM, symbol.

12. A radio network controller, RNC, in a radio access network, or a base station in a wireless communications network or an access gateway, aGW, or a radio resource management, RRM, server comprising the controller (118) of any preceding claim.

13. A method for scheduling resources in a cellular wireless network, the method comprising:

determining channel quality of a first radio channel between a first base station and a first user equipment, UE; wherein the method is **characterised by**:-
operating in a coordinated manner between the first base station and a second base station so that a single stream transmission between the first base station and the first user equipment coincides with single stream transmissions from the second base station;
wherein the data streams are subject to Orthogonal Frequency Division Multiplexing, OFDM, modulation.

14. The method of claim 13, wherein determining the channel quality comprises receiving a signal quality report from the first UE indicative of the quality of signals received by the first UE from the first base station.

15. The computer program for scheduling resources in a cellular wireless network, the computer program comprising code operable for, at a controller:

determining channel quality of a first radio channel between a first base station and a first user equipment, UE; wherein the method is **characterised by**:-
operating in a coordinated manner between the first base station and a second base station so that a single stream transmission between the first base station and the first user equipment coincides with single stream transmissions from the second base station;
wherein the data streams are subject to Orthogonal Frequency Division Multiplexing, OFDM, modulation.

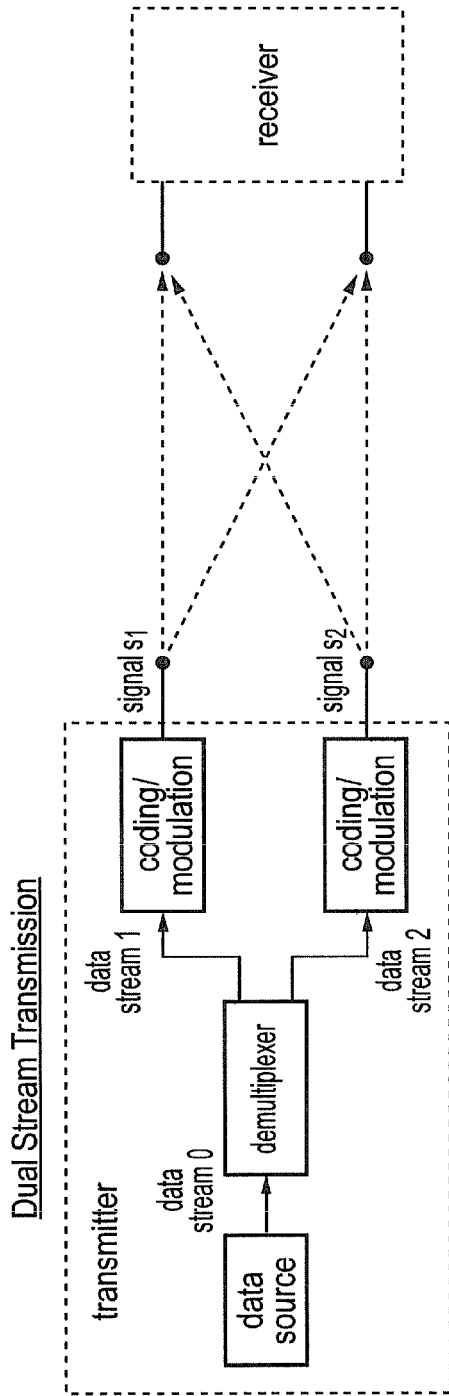


FIG. 1A

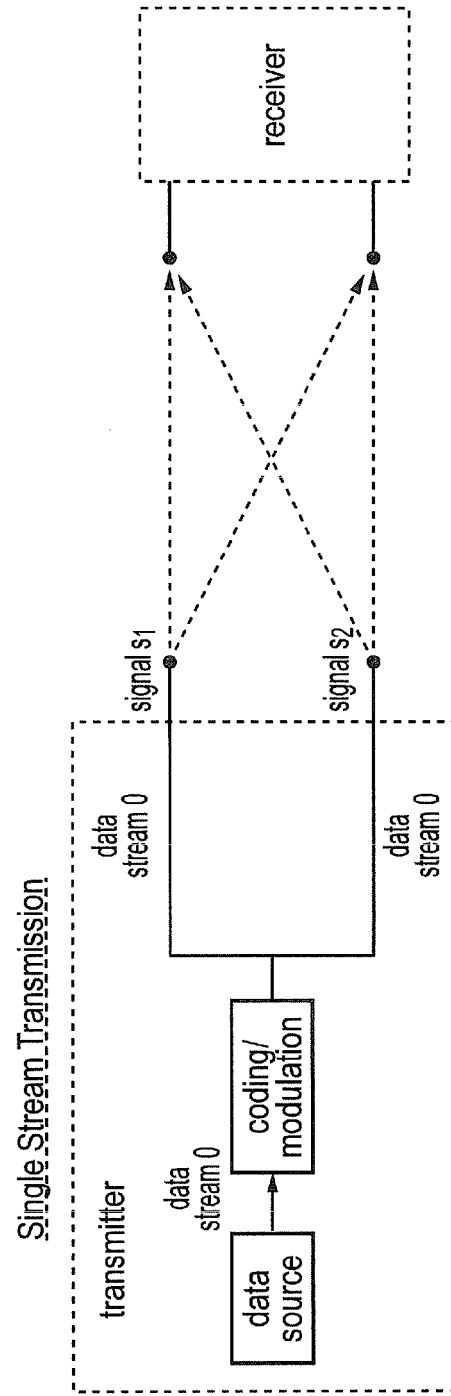


FIG. 1B

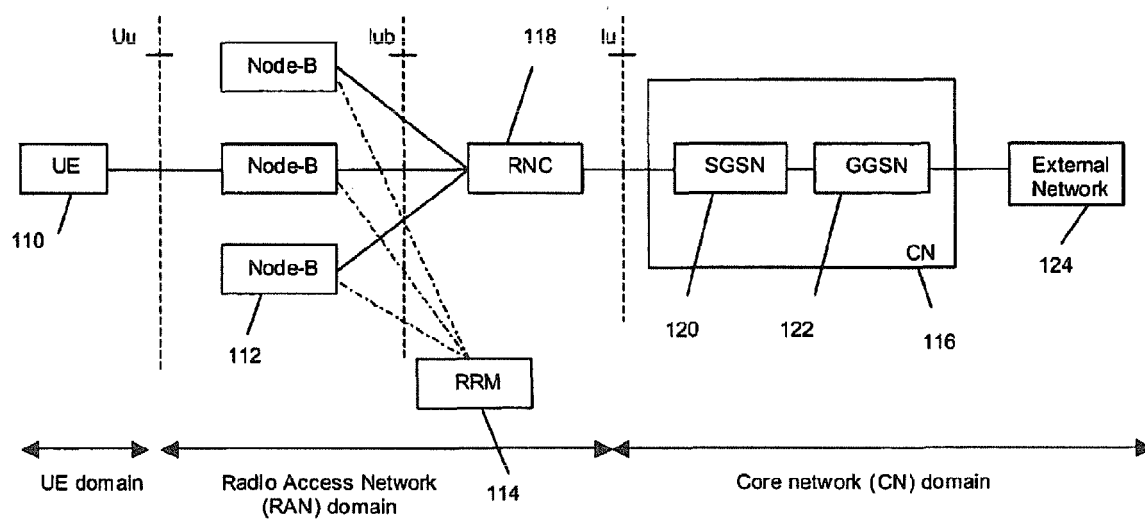


Figure 2A

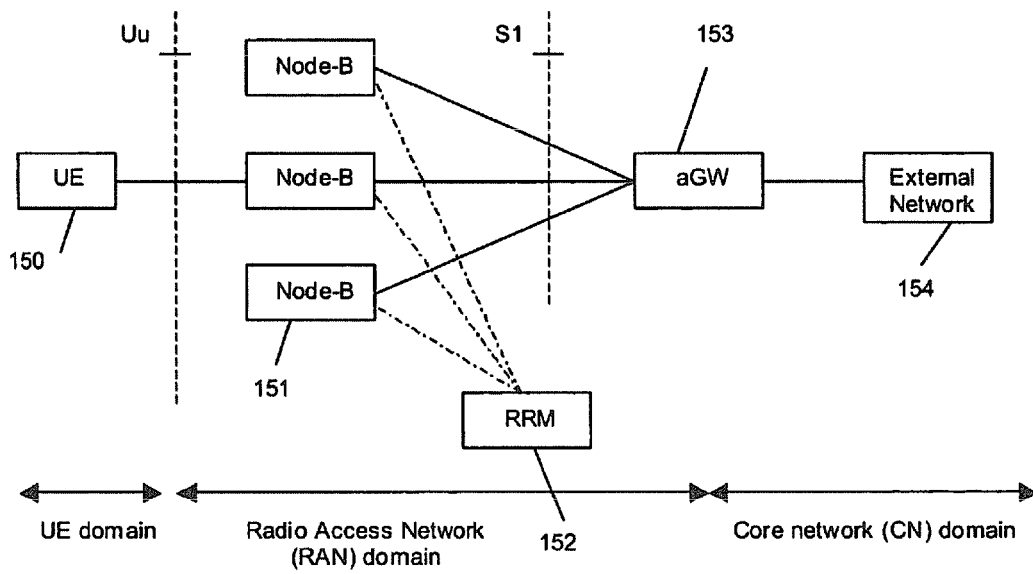
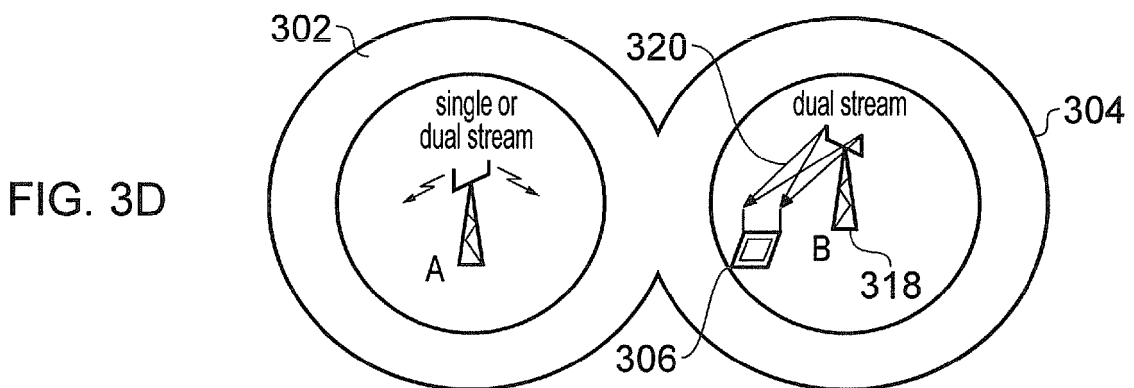
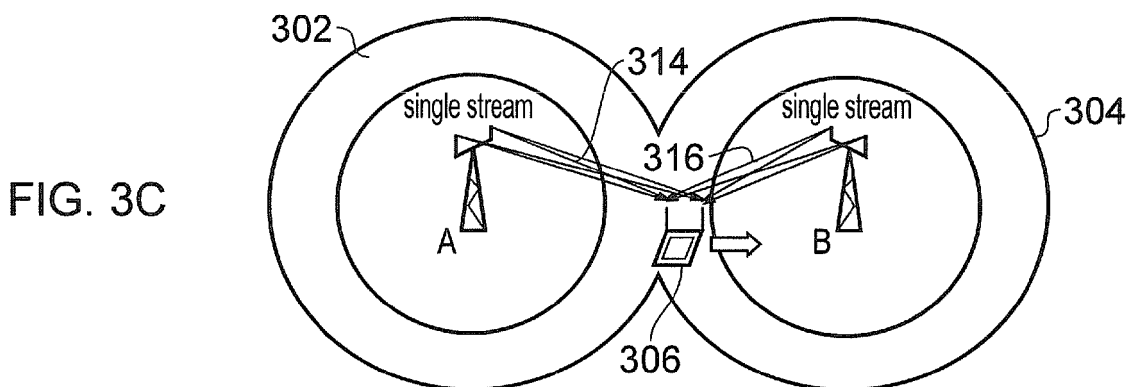
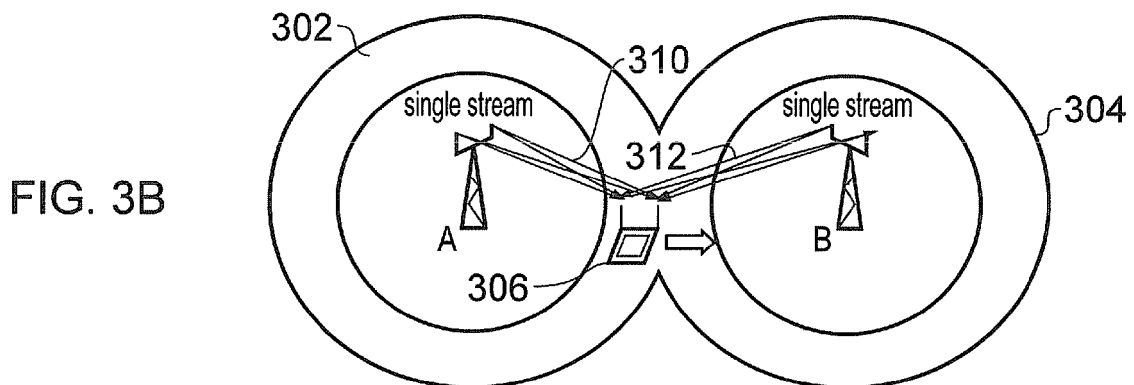
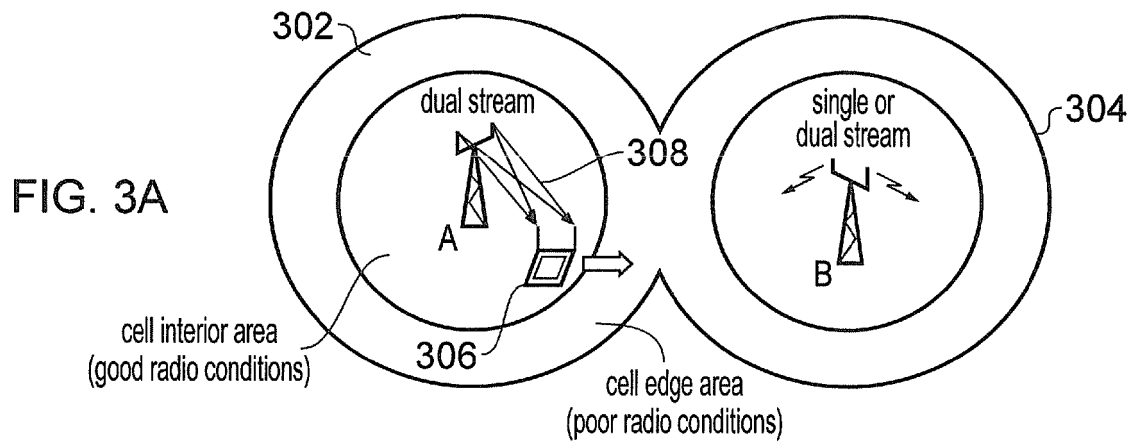


Figure 2B



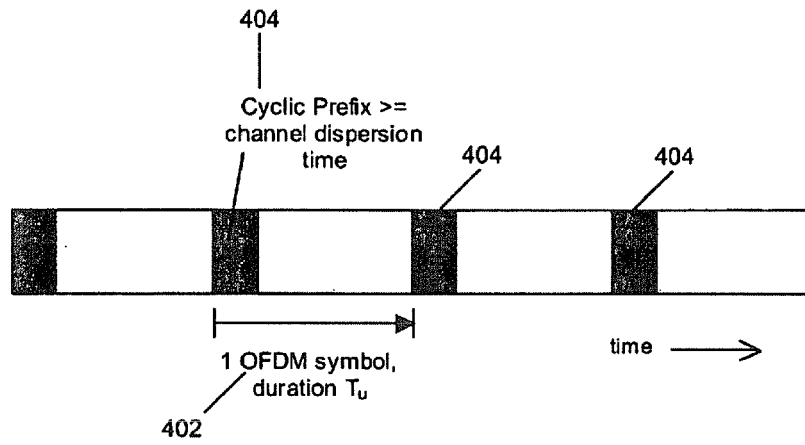


Figure 4

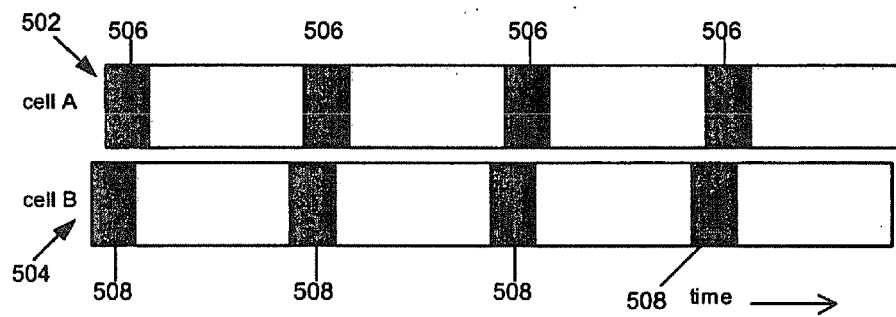


Figure 5

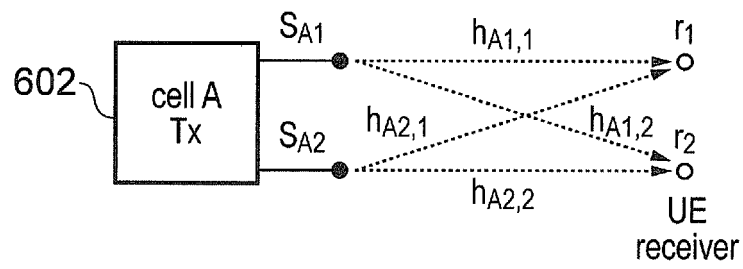


FIG. 6

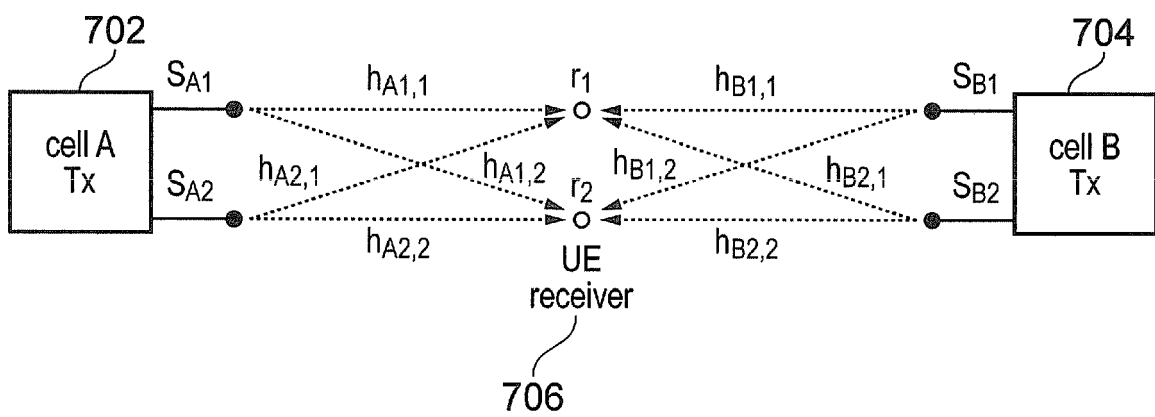


FIG. 7

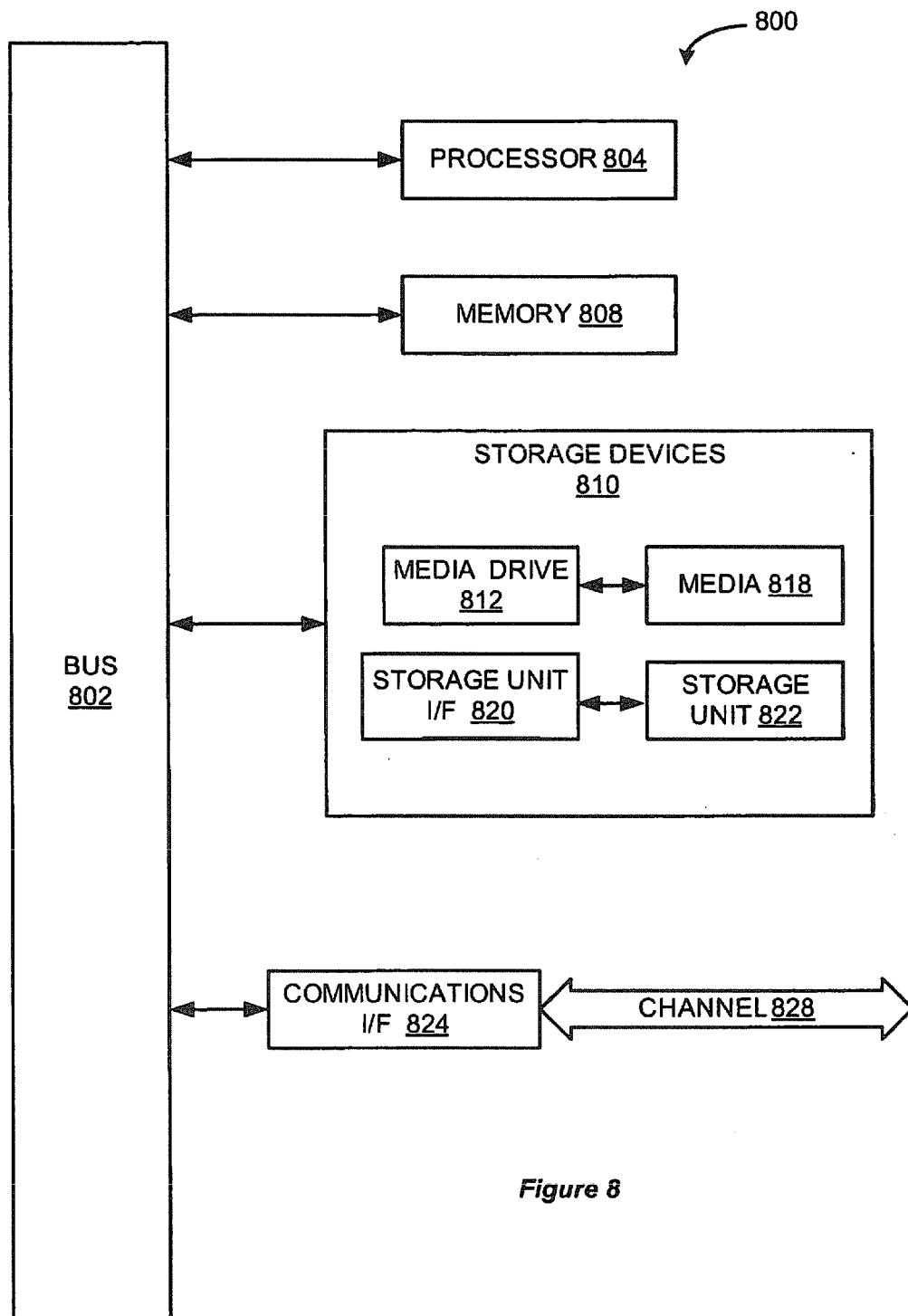


Figure 8



EUROPEAN SEARCH REPORT

Application Number
EP 11 16 5563

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A	ANDREA GOLDSMITH ET AL: "Capacity limits of MIMO channels", IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, vol. 21, no. 5, 1 June 2003 (2003-06-01), pages 684-702, XP55008315, ISSN: 0733-8716, DOI: 10.1109/JSAC.2003.810294 * page 685, right-hand column, line 48 - page 686, left-hand column, line 19 * ----- -/--	1-15	
2 The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 30 September 2011	Examiner Donnini, Carlo Luca
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 11 16 5563

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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search Munich		Date of completion of the search 30 September 2011	Examiner Donnini, Carlo Luca
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
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DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 30 September 2011	Examiner Donnini, Carlo Luca
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 11 16 5563

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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30-09-2011

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